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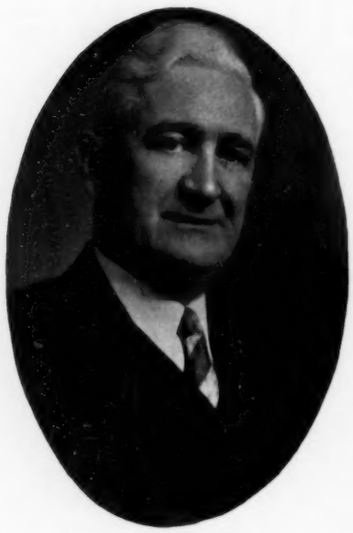

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C. H. Fielding, Wks. Supt., Rustless Iron Corp., Baltimore, Md.
O. M. Svennson, Engr., Vanadium Corp. of America, Bridgeville, Pa.

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R. W. Davis, Allis Chalmers Mfg. Co., Milwaukee, Wis.
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L. H. Tippins, U. S. Electrical Mfg. Co., Pittsburgh, Pa.
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R. G. Widdows, Electric Controller & Mfg. Co., Cleveland, Ohio.
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D. W. Dean, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
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C. H. Williams, Steam Engr. Dept., Carnegie Steel Co., Ohio Works, Youngstown, Ohio.
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The Current Collection Problem of Rotating Electrical Machinery

By C. LYNN
Design Engr., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Presented before Chicago District Section of the A. I. & S. E. E., January, 1932.

The successful collection of current between movable and stationary conductors depends entirely upon the continuity and positiveness of contact between the current collecting members. This continuity of contact is dependent upon the surface conditions of the contacting members, as well as many other factors, which will be discussed in this paper. A physical conception of the phenomena encountered will be considered, and the theories accounting for these various actions and effects will be supplemented by data from test results and actual experience.

Just what occurs under a brush while conducting current out from or in to a movable conductor is not fully known, other than that it is a gaseous phenomenon. The simplest apparatus for this consists of a metal leaf brush, generally made of copper or phosphur bronze, rubbing against a rotating metal ring. In this case, there is a small voltage drop between the two conductors, due to the resistance of lack of intimacy of contact. Except for use in small size machines, or where low peripheral ring speed is encountered, this is not a very satisfactory means of collecting current from a rotating conductor. The use of block carbon in its various forms and in mixtures with other materials, in replacing the copper leaf brush, was the first step in improving current collection. The block type of brush was better, from a mechanical consideration, because the material itself acted as a lubricant in giving good riding qualities and, in the case of commutating machines, had a surface contact resistance drop that was very beneficial in limiting the local current flow, due to the voltage being short circuited in the coils undergoing commutation.

The voltage drop between a brush and a movable conductor is different when the conductor is at rest than when it is in motion, being several times as great in the latter case. It has been shown experimentally in our laboratories[2] that current is conducted from a brush to a movable ring or commutator by a small number of minute points on the brush face that are actually in contact with the movable conductor, and that these minute points are continually being worn and burned away and are being replaced by others in different parts of the contact surface. Also, it has been found that the area of these spots at any given instant may be as little as 5% or less of the total contact area of the brush. These spots may be increased in number and size from 50 to 100 times by a large increase in the brush pressure. The existence of these contact spots was proved by discharging a heavy current from a condenser for an extremely short duration of time, across the brush contact. This discharge of current was so rapid that it left imprints of these minute spots on the face of the brush and on the surface of the ring, even with the ring rotating at high surface speed. Successive tests showed that the old spots were disappearing and that new ones were continually appearing to carry the current. It must, of course, be understood that these contact spots are extremely minute in size and cannot be seen at the surface of a brush that has operated for some time and has a good fit and polished surface, until the condenser discharge test has made their location visible. See Fig. 1.

FIG. 1—Spots Burned on the Face of a Brush by Current Discharge of a Condenser.

There is a phenomenon that is sometimes experienced on commutating machines known as brush glowing. When this occurs, a portion of the brush, somewhat semi-circular in shape with a diameter of from 1/16" to 3/8" or more becomes heated to a red glow, showing itself along any edge of the brush. This glowing may occur at one spot and then disappear completely from the brush or it may occur at one spot and travel along the edge of the brush, finally disappearing. It may occur, disappear and re-occur on the same brush or go from one brush to the other. It never occurs unless a brush is working at fairly high density, and it is caused by some one spot of the brush becoming heated to incandescence, thus raising to a red glow, surrounding brush material. A minute amount of copper picked up by the brush face may lower the contact drop at that particular point so as to start the glowing. It may also be caused by the surface condition of the commutator. Once started, the negative temperature co-efficient of a brush tends to accentuate the trouble, and the localized heating of the brush causes an expansion of the brush at that point, raising the rest of the brush away from intimate contact with the commutator, thus increasing the pressure and current density on the glowing area. After some seconds duration, this high portion of the brush will be worn and burned away, and the rest of the brush will return to more intimate contact with the commutator surface, causing it to carry some of the current and relieving the glowing spot from its excessive localized current, thus causing the glowing spot to disappear or to travel to some other portion of the brush.

[2]A. I. E. E. Transactions, June, 1931, Volume 50, Page 718, G. M. Little. Power, March 24, 1931.

This glowing is often accompanied by streamers from the brush, which are small particles of brush material that have been subjected to high current densities and heated to incandescence and thrown off by mechanical rotation of the commutator. Figure 2 is a photograph of the face of the brush that has been subject to glowing and throwing off of streamers.

If measurements are made of the current carried by various brushes operating in parallel on the same arm of a commutating machine or the same ring of a collector, it is found that often one brush may be carrying most of the current while the others are carrying but a small portion. This same unequal division of current also occurs between the various brush arms in parallel on a commutating machine. It has also been found that the amount of current carried by any brush varies with time and, while one particular brush may be carrying several times its share of the current at one instant, a little later the conditions may be reversed and some other brush will be overloaded while the first brush will be shirking its share of the current. This is undoubtedly due to the surface condition and the number of minute contact spots that exist at any given instant for the carrying of the current. An attempt was made some time ago to force every brush in parallel on a given collector ring to carry its proportional share of the alternating current going into the ring by running the current to each brush on this given ring through a winding of a transformer with all windings of the transformer mounted on separate legs of a common core in such a manner as to force an equal division of current in each transformer leg. This made each brush carry approximately its proportional share of current, but the results were disastrous, causing excessive sparking and wear of the brushes. The reason for this was that when a brush was forced to carry more current than it would normally carry at any given instant, the contact spots carrying the current were highly overloaded when its natural tendency was to shirk current, and sparking and rapid wear of the brush resulted. It is this tendency to shirk the current when its normal inclination is not to carry load that causes the brushes to work as well as they do.

FIG. 2—Face of Brush that has been Glowing and Shooting Streamers.

The problem is then not to force the brushes to carry equal amounts of current, but to seek the cause of the unequal division of current and to remove the cause of this trouble.

In the case of commutating machines, it is possible to change the division of current between various brush arms in parallel by increasing the brush pressure on the brushes of an arm that is carrying less than its share of current, thus increasing the number of contact spots that are carrying current and decreasing the brush pressure on the brushes of an arm that is carrying too much current. In extreme cases, it has been found that one arm may be carrying from 5 to 25 times as much current as that of some other arm in parallel with it. It is possible to cause a better division of current between various brushes in parallel on the same arm by the use of high resistance shunt leads from the brushes to the arm. This additional resistance added to the contact resistance and the resistance of the brush itself minimizes the affect of variation of the contact resistance in varying the proportion of load current carried by each brush. This, however, does not affect the local circulating current flowing in the brush, due to the short circuiting of the coil undergoing commutation. In order to make this scheme effective in improving division of current between brushes, it is necessary that the resistance be somewhat comparable to the contact surface resistance. Since all the load current must go through these shunts, a considerable loss will be entailed, which is undesirable from the efficiency standpoint, and the additional heat produced must also be gotten rid of. This scheme has only been tried in a few cases.

It was found several years ago that an air pressure of 2 to 5 ounces existed under a brush on a movable ring, and that if the air pressure were reduced by transverse slots in the ring or transverse slots in the brush or drilling radial holes in the brush, the voltage drop between the brush and ring was reduced, giving better operation and a more even division of current between brushes operating in parallel on a given ring. A few converter collector rings were slotted at that time, but the use of slotted rings was abandoned commercially as the slots would fill with dirt and brush material and, being transverse, were hard to clean. When both conductors are stationary, the voltage drop between the brush and the ring is less, as the air pressure is eliminated, giving more and better contact points between the brush and the ring.

To overcome the cause of all these troubles, our Research Department[2] suggested a modification in the grooving of commutators and collector rings, so that during a part of each revolution some of the brush surface would be entirely relieved of contact with the moving conductor. In the case of commutators and transverse slotted collector rings, this same relief from carrying current for a portion of the time is secured, but with the slots transverse to the direction of rotation the same results were not secured as in the case of circumferential grooving because a localized hot spot has sufficient area to extend across these transverse grooves for the very short time this groove is under any one particular spot. With a circumferential groove of low pitch, the groove moves comparatively slowly in a direction parallel to the shaft under any given por-

tion of a brush, permitting that portion of the brush to cool appreciably before it is again called upon to carry current by an ungrooved portion coming in contact with it. These circumferential grooves, besides giving a cooling effect, also break up the air pressure under a brush, the same as transverse grooves. Figure 3 shows a type of helical groove. The width of the groove and the ratio of grooved width to ungrooved width and the pitch of the grooves can be varied over a considerable range without appreciably affecting the results. Ordinarily a groove ⅛" wide with ¼" or ½" pitch gives satisfactory results. The use of a groove, of

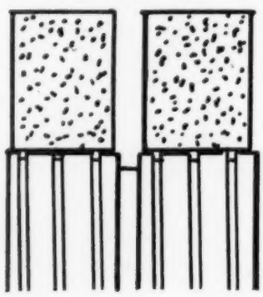

FIG. 3—Double Width Helical Grooved Synchronous Converter Collector Ring with Brushes in Position. Grooves are ⅛" Wide, ⅛" Deep, and the Pitch is ½".

course, increases the current density on that portion of the brush that is momentarily carrying current, but when rotating, the groove continually moves over the brush contact surface that area that is carrying current, thus keeping any one spot from carrying a heavy current continuously. The grooves are generally made approximately ⅛" deep, although they can be made any depth desired. The air in these grooves helps cool the current collecting parts and reduces somewhat the temperature of these parts in actual operation.

In actual service some 13,000 ampere synchronous converters have been in operation for about one and one-half years with grooved collector rings. The results to date on these machines show a much more uniform brush wear than is obtained on other duplicate units using smooth rings. Tests on these machines also show that with slotted rings the brush pressure can be reduced somewhat, thus helping to reduce the brush friction and frictional wear of the brushes.

Grooving of collector rings carrying D.C. current on synchronous machines has also been used with very good results, overcoming in some cases conditions of sparking and rapid wear of brushes.

In the case of commutating machines, fewer commutators have been grooved than collector rings. In the case of some medium size industrial motors, grooving the commutator has permitted an increase in overload swings on these motors. Some street railway motor commutators were grooved and eliminated burned and flat spots that were experienced. Grooving of large size commutators has not been done because grooving of commutators is still considered as being in an experimental stage.

In order to further investigate the phenomena of current flow from a brush to a movable conductor, a series of tests has been conducted by operating brushes on slip rings and commutators in various gases other than air.[3] Since synchronous condensers and turbo generators have used hydrogen for cooling, in order to increase the output and decrease the losses, tests were first made in this medium. It was found that if no appreciable sparking was present, successful current collection could be secured when operating in hydrogen on both collector rings and commutators, with less wear on the brushes than in air. In the case of collector rings, it was found that grooving the rings gave much more satisfactory results when operated in hydrogen. In the case of commutating machines, it was found that when sparking was present, much more detrimental affects occurred, with very much higher rates of wear of the brushes and with much more burning of the commutator. Tests in nitrogen gave practically the same results as tests in hydrogen. In connection with these tests, it was found that where sparking is present, if the humidity was kept below 10%, much greater brush life and decreased damage to the commutator could be secured.

In order to secure a criterion for determining when satisfactory results would be obtained from a commutator and its brush rig or a collector ring with its brush rig, and to secure a means of measuring this performance without actually subjecting the machines to an operating test, the brush drop oscillograph test and roughness factor meter were developed by our Engineers[4]. This test simply consists of taking an oscillograph record of the voltage drop between a stationary brush and a movable conductor, such as collector rings or commutator. In testing commutators, three insulated brushes are mounted on an arm in such a manner that one brush rides in the center of the commutator and one near either end of the commutator. By connecting a source of direct current in series with any two of these brushes and a resistance, and taking an oscillogram of the voltage drop

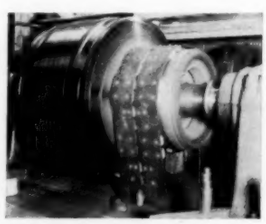

FIG. 4—Commutator Being Seasoned by Wooden Block Method.

between these two brushes as the commutator rotates, a picture of the voltage drop between the brushes and each commutator bar can be secured. By connecting in parallel with the oscillograph a roughness factor meter consisting of a condenser, a variable resistance and a thermal milli-ammeter, an R.M.S. value of current flowing through this circuit due to the R.M.S. voltage drop can be secured. This meter, called a "roughness factor meter", will give the average comparative roughness of a commutator, while the oscillogram will indicate the comparative roughness of each individual commutator bar.

Since a commutator has to go through a temperature cycle with corresponding changes in stresses, it is possible to determine the performance of a commutator by taking brush drop measurements with the commutator at various temperatures. This can be secured even with a commutator not connected

[3]A. I. E. E. Transaction, June, 1931, Volume 50, Page 714, R. M. Baker.

[4]A. I. E. E. Transactions, April, 1929, Volume 48, Page 666, Hague and Penney.

to an armature by heating it with the friction of wooden blocks rubbing on its surface while rotating, as indicated in Figure 4. These blocks are fastened to belts, the ends of which are clamped against the floor with any tension desired to give a sufficient pressure for heating the commutator bars by friction. The brushes ride on spots of the commutator that are not subjected to this frictional force, so that the surface on which they ride will not be affected by the material rubbing on the commutator. By varying the pressure on the wooden blocks, variations in the temperature at which brush drop tests are measured can be secured, and roughness factors can be measured at any temperature desired throughout an operating cycle. This method of heating approximates load operating conditions in that the bars are individually heated at their surface and the commutator subjected to all the stresses due to rotation and expansion forces of heating. Many hundreds of tests made in this manner on commutators have

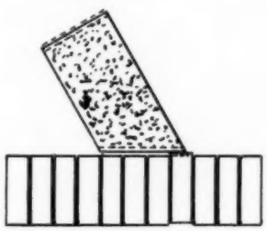

FIG. 5a—Commutator with a High Bar Showing Brush Being Lifted from Commutator Face.

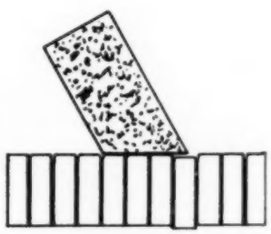

FIG. 5b—Commutator with a Low Bar Showing No Actual Contact of this Bar with Brush.

shown that the test is an accurate one, and that a commutator that gives a roughness factor below a value that has been found to be satisfactory will give successful performance in service.

In connection with this test, it is of interest to study what happens when high or low bars are present. Figure 5A shows a commutator with high bars passing under a brush, while Figure 5B shows the corresponding action with the low bars.

Due to centrifugal force and expansive forces of temperature, commutator bars are caused to deflect radially. Since bars are not rigidly fastened together but separated by mica and held in place by V-mica on V-rings ordinarily, which mica may or may not be perfectly uniform, an unequal deflection of commutator bars is possible. Bars may deflect singly or in groups. There is a difference between commutator eccentricity and bar movement. It is practically impossible to turn or grind a commutator, so that it will be absolutely concentric when running at rated speed, especially if it is a high speed commutator with a surface speed in the neighborhood of 5500 to 6500 ft./min. In this case, it is necessary for the commutator to be concentric within 0.001" if satisfactory operation is secured, because if the eccentricity is appreciably greater than this at this high speed, the brush cannot follow the commutator surface. When there are high or low bars, the amount of surface deviation between one bar and the next adjacent bars must be considerably less than .0001" if successful operation is to be secured.

In the case of the single high bar, when this bar moves under a brush, the brush is lifted or thrown off of the commutator by the amount of the high bar or greater, depending upon the speed of the commutator. If the speed is high, it may even be possible for the brush to be thrown off the commutator a sufficient amount to give a very large voltage drop, and the brush may not even return to the commutator until one or more bars have passed under it. In the case of the low bar, there will be an increased voltage drop between it and the commutator, due to the increase in the gap under the brush. There will also be indicated a roughness voltage due to an imperceptible movement of the brush in its holder, due to the change of friction at its surface, for when the low bar fails to touch the brush, there will be considerably less friction on the brush and the brush will have a tendency to have some circumferential movement in the brush holder. With an extremely slight amount of difference between the surface height of two bars, no trouble will be experienced because the brush has some surface deflection and resiliency which will permit it to follow extremely slight imperfections in smoothness. Were this not so, considerably more variation in roughness voltage would be indicated by the brush drop test.

As was stated before, there must not be but a very slight difference between the heights of adjacent bars or groups of bars or else trouble will be encountered. Whereas a surface contour variation of .001" or more, depending upon speed, can be tolerated, it has been found by experiments that the abrupt variation of one bar to the next must not be greater than .0001", or else trouble will be experienced by too great a voltage variation between the brush and commutator bars. To determine this value of .0001" experimentally, a copper disc ring was made in which a transverse slot was made corresponding to that of a commutator bar. This slot was then filled in with a section of the same material and held in place by countersunk screws. The surface of the ring was turned as true as possible, a piece of .0001" gold beater's skin was placed under the bar in the groove so as to raise this portion of the surface .0001" above the true surface of the ring. Brush drop oscillograms were then taken and the voltage kicks caused by this high bar compared with those taken on commutators. This comparison showed that commutators worked satisfactorily when the voltage deflections, taken on a brush drop test, were no greater than that obtained on the brush drop tests made on this ring with a 0.0001" high bar, and worked unsatisfactorily when the deflections were greater. This, then, established the fact that abrupt variations of adjacent commutator bars must not exceed 0.0001" or unsuccessful operation will result. The lower the value of voltage deflection the more successful the commutation would be, other factors being equal.

Investigations were then carried on to determine what affect the brush rigging had upon the operation. It was found that with a given commutator these affects were quite pronounced in securing satisfactory or poor results. If the brush was too loose

fitting in the holder or if the angle was incorrect for the particular grade of material and surface condition, then chattering would result. Where chattering was encountered, a poor brush drop test was secured, indicating that the brush was not making continuous contact with the commutator surface. Any steps that were taken to hold the brush in such a position that it could follow the surface contour of the commutator and still not move in such a direction as to appreciably vary its contact with the commutator tended to reduce the brush drop voltage kicks and improve the operation. These things will also tend to reduce the losses at the brush contact surface, and thus reduce the operating temperature of the commutator.

Under controllable variables as affecting current collection will be discussed those factors that the designer has under control. Next in order, load cycles, operating conditions and maintenance will be considered.

Commutators have probably been given more thought and attention than any other one factor entering into the current collection problem. Of the three main materials entering into the construction of a commutator, less by far is known of the mica than of the copper or steel parts, since all of the chemical and physical properties of the latter two materials are very well known. On the other hand, mica as used in commutators is built up of flakes of selected mica held together by suitable bond, generally shellac. The mica plate is usually built up on automatic machines, and since it is a built up product, it may vary somewhat in its properties in different parts of the same plate. Also, it has to be made to a given thickness for V-ring mica and for bar mica, and a very small deviation in manufacture in the thickness of the latter will total a considerable amount when the large number of pieces of commutator bar mica in a commutator are considered. The commutator bars are generally drawn through a die, and their thicknesses are quite uniformly the same and very close to the required value. Nevertheless, mica is the best material that has ever been found for use as an insulator in commutators between bars and between holding supports (generally V-rings or shrink rings), as it is a good electrical insulator, withstands the heat encountered and in the built-up flake type has the property of becoming seasoned with heat, pressure and time. It is the nature of this built-up mica, and to a slight extent of copper also, to tend to yield when first subjected to stress and temperature. The gradual yielding and settling of the mica and the copper under stress, temperature and time until a final stable condition is reached is referred to as seasoning. Methods of seasoning vary, depending upon the type of construction of the commutator, its size and service. Very small commutators receive no seasoning whatever and work satisfactorily. Medium size commutators are often seasoned by simply baking in a stationary oven and tightening under pressure. Large size and high peripheral speed commutators require a more complete seasoning process. These are usually seasoned by being given one or more cycles of heating and cooling while being rotated. The larger and more difficult the commutator is, the more heating and cooling cycles it will have to go through during seasoning before a stable condition is reached. Years ago this was attempted after the machine was completely built, and while it was on the test floor, by running the machine at short circuit voltage and circulating heavy current. This heavy current and any accompanying sparking such as was secured by moving the brushes off of neutral, together with as much frictional loss as could be secured by using excessive pressure on the brush, gave the heat for seasoning the commutator. Obviously this was not a very good method as the temperatures could not be controlled very well and it delayed the shipment of the machine because the seasoning could not be done until after the machine was completely built, whereas if commutators are seasoned while the machine is building, the seasoning of the commutator can be carried out while other parts of the machine are being built; thus a longer seasoning period can be given to the machine without lengthening the delivery date. The modern approved methods are either by heating the commutator while rotating in an oven or using the heat generated from the friction of the maple blocks attached to a belt and rubbing on a commutator. This method of heating a commutator was shown in Figure 4.

Of the two most used methods of holding commutator bars in place, the V-ring type of construction is used wherever possible because it permits tightening during building and seasoning, and even in service, if necessary, and it gives comparative ease of repair, if required. The expansion stresses due to heating can be easily taken care of by using through bolts extending from one V-ring to the other. These bolts, if made of the right material and correct size, can be stressed in such a manner as to elongate as the commutator bar lengthens, due to expansion of temperature, without exerting excessive pressure. The V-rings can be made such as to be held accurately centered in service and also permit flexibility for axial movement with expansion.

The shrink ring type of commutator is only used where required on account of excessive speeds. By its use, a short span between the points of support under the shrink rings can be secured by using a larger number of rings. The objections to the use of shrink rings are that they do not permit any method of tightening the commutator and give a commutator that is almost impossible to repair, besides it is difficult to tell what holding pressures are secured. The shrink rings also increase the length of the machine, which may be objectionable.

The success of a commutator is judged by its ability to go through the temperature cycle over which it is designed to operate and not develop surface roughness. This is determined by the type of construction and building process used. The experience, manufacturing equipment and research work of the builder determine this.

An operating temperature limitation placed upon a commutator does not assure successful operation. Lower temperature operation can only be secured by providing more radiating surface on the commutator, so that it can more readily dissipate the heat loss. Generally, this means increasing the size of the commutator. If the commutator is made longer, the deflection due to centrifugal force increases as the fourth power of the length of span. If it is made larger in diameter, the deflections increase approxi-

mately as the increase in diameter. This, however, increases the peripheral speed, which also increases the roughness factor. Thus, securing a lower operating temperature commutator at the expense of increased stresses will give a commutator that has a higher roughness factor than a smaller, lower stressed, higher operating temperature commutator, with the possibility of poorer operation. In the case of poorly constructed commutators involving high stresses, unsatisfactory operation will be experienced. A decrease of load to ½ or less, with an accompanying still lower operating temperature, will not appreciably change the performance, showing that it is the roughness factor and not the temperature that determines the degree of success of its operation.

In rotating machinery, it is desirable to use a relatively high R.P.M., in order to secure a small size unit of low cost and high efficiency. This means that in using high speed machines where stresses in the commutators would be fairly high, no requirement should be imposed to secure an unduly low temperature rise of the commutator. Such a requirement would increase the stresses to such a value as to make the commutator inoperative from a roughness standpoint, whereas satisfactory operation could be expected with reduced stress and somewhat increased temperature.

Commutation difficulties, besides indicating themselves in sparking and glowing of the brushes, leave their impressions on the commutator. This generally shows up in the form of burning and blackening of the bars. Since different causes often give the same kind of blackening and burning of the bars, it is somewhat difficult to tell just the cause of any difficulty being experienced from an examination of the burning. Electrical misadjustments show up as sparking of the brushes either on the heel or toe or both, and sometimes even under the face of the brush. This can usually be corrected by spacing the brushes equally around the commutator, placing them on the correct neutral and securing the proper strength of interpole field or, in the case of non-interpole machines, shifting the brushes to the proper point to get the required commutating field. Where the burning is due to overloads beyond the capacity of the machine, vicious sparking, often streamers and burning and blackening of the commutator bars results. Sometimes a commutator neck does not make good connection with an armature coil, due to a poorly soldered joint. In this case, the bar connected to this neck will show signs of burning and blackening, which will start at the leaving edge of the bar and progress with time until eventually the entire bar is burned across. When this bar passes under a brush, less current is carried by it into the brushes, due to its burned condition, and the corresponding bars under other brushes of like polarity are overloaded by the amount of current shirked by the burned bar. Due to this, they often also show up as burned bars. The correction of this difficulty is, of course, to re-solder the bad joints. A broken commutator neck or a broken armature coil will show up in the same manner as a poorly soldered joint, only the results will be considerably worse, due to the complete opening of the circuit.

Where a commutator is not thoroughly seasoned or has a roughness factor that is too high to permit successful operation, burned and blackened bars will show up promiscuously around the commutator, starting on one bar and progressively burning more bars as time goes on. When such a condition occurs and the commutator is ground, sometimes the same bars show up again as burned bars and sometimes they do not, the other bars showing up as burned bars. In such a case, these difficulties are sometimes cured by continual operation, in which case the heat from the losses in the commutator, together with the pressure on the mica, will in time completely season the commutator. In some few cases, the commutators will not cure or season themselves, and it will be necessary to do additional work on the commutators, such as tightening and subjecting them to additional heat treatments and grindings.

Some classes of machines are supplied with what are known as involute necks. These consist of copper connections connecting the commutator bars to the armature coils in such a manner that each bar is connected to two armature coils, 180 electrical degrees apart, instead of to only one coil. Such a construction is shown in Figure 6. The theory of the operation of involute necks is, that if one commutator bar, due to a slight movement, tends to shirk its load, the current coming out of the coils that would normally flow into this bar can be carried by other bars of the same potential, by current flowing from these coils through the involute necks to these other commutator bars located 180 electrical degrees away from the bar in question. This provides an automatic relief for this distressed bar before the bar becomes too much distressed by an excessive amount of burning, and this permits the commutator to operate satisfactorily with an inherently higher roughness factor. In addition, these involute necks act as armature cross connections, and since they are connected to every armature coil, the armature is 100% cross connected. However, experience shows that if an armature has 25% to 50% of its coils cross connected, any additional cross connections do not noticeably improve the operation.

FIG. 6—View Showing Involute Necks on D. C. Generator Armature.

Next to commutators in importance in this problem come brushes. It has been found by experience that brushes have a fairly definite carrying capacity. This will vary with the type and material of the brush and the conditions under which it operates. Normally, from 50 to 65 amperes of load current per sq. in. of cross sectional area can be carried by a commutating brush continuously. Higher brush densities tend to overheat the brush and cause sparking and glowing. Besides, the load current flowing from the commutator to the brush, there is a circulating current that flows from the commutator bars into the brush and back into adjacent commutator bars, due to the brush short circuiting the voltage generated by the coils undergoing commutation. This circulating current adds to the load cur-

rent on one side of the brush and subtracts on the other, thus giving a current density that is actually considerably higher than that figured from the load current. It is, of course, advisable to use as thick a brush as possible, in order to reduce the total length of brush contact required on the commutator, giving as short a length of commutator as is consistent with its heat radiating capacity. The permissible thickness of brush used is limited by the dimensions of the machine; that is, the commutator diameter, number of bars, slot pitch, bars per slot and chording. Too thick a brush means that the commutating zone or the space on the armature periphery over which commutation occurs will be so great that not only will the interpole flux be used in affecting commutation, but stray flux from the main poles will extend out into this zone and affect the results adversely. The use of a thicker brush reduces the reactance voltage per commutator bar, but increases the total reactance voltage handled by the brush.

There are two major classifications of brush material, natural graphite, which material is mined, and electro-graphite, commonly thought of as carbon. The latter type of brushes are harder, usually have shorter life, cause less wear on the commutator and have slightly less maximum current carrying capacity than do the natural graphite type of brushes.

One type of brush is made with bakelite as a bond, and this brush is made in such a manner that the resistance to crosswise flow of current is considerably more than that to lengthwise flow of current, and this is useful in that it acts as an added resistance to the circulating or cross-flow current, while not introducing any additional resistance to the flow of load current out of the brush.

Brushes are sometimes made with a very slight amount of abrasive material in them to act as cleaner brushes. When these brushes are used, it is not necessary to use a complete set of them, but to use one or more brushes per arm staggered spirally around the commutator, in order to completely wipe the surface of the commutator every revolution. This cleaning action, while of a very slight amount, is often sufficient to keep down the starting of any burning, and thus secure satisfactory operation. Usually, after cleaner brushes have been operated for some time, the commutator will have settled down sufficiently so that their use need not be continued permanently.

Two characteristics which are important to brushes in high speed service are elasticity and weight. A brush material that is quite elastic will permit the surface of the brush to follow the very minute irregularities of the commutator surface, while a brush with light weight is useful in permitting the brush to follow the eccentricities of the commutator. Brush pressure used depends entirely on the characteristics of the brush and the speed at which the commutator operates. This may vary from 1 to 2½ pounds per sq. in. of cross sectional area as an average.

Brush holders have ordinarily not been given the importance that they deserve in the current collection problem. They have a very large influence on the roughness factor obtained because with any given commutator the roughness factor is dependent upon how well the brush rides the commutator; that is, how intimately it makes contact with the commutator. Brushes that move around in the holders and chatter on the commutator cannot operate satisfactorily. It has been found by experience that it is ordinarily better to operate brushes inclined rather than radial to the commutator surface as they are less subject to chattering. Opinion differs as to whether brushes should run inclined against rotation or inclined with rotation, but the prevailing opinion seems to be that brushes should be inclined against the direction of rotation, especially for high commutator surface speed, as there is less tendency for them to bind in the holders.

Most brush holders are of the sliding shunt type, wherein the brush can slide up and down in the brush box, and the current is carried from the brush to the brush holder by means of a flexible copper shunt. In this type of holder, the spring pressure is ordinarily exerted in line with the radial axis of the brush. Improvements are sometimes secured by supplying the brushes with a bevelled top where the spring pressure arm rests, in order to cause the brush to rest against one side of the brush holder. In this respect, this brush holder is similar to the reaction type holder, except that in this latter type of holder the brush box does not ordinarily completely surround the brush, the brush resting against the spring side of the brush holder only.

A fairly recent improvement in brush holder construction consists of the double brush holder. This brush holder is of the sliding shunt type, with two compartments, two sets of lever arms and springs. Thus instead of using one brush 1" thick, two independent brushes each ½" thick with a thin dividing wall between them are used. This construction has two advantages—first, it permits each half brush to follow the irregularities of the commutator, and while one half brush may be jumping off the commutator, the other half will be in contact with it, reducing the sparking and tendency to burn.

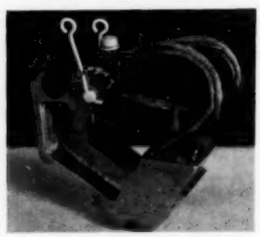

FIG. 7—D. C. Double Brush Holder, Using Brushes of Same Length Capable of Full Brush Wear in Each Compartment, Without Sacrificing Accessibility of Brushes for Maintenance Requirements.

The use of the smaller brush with lighter weight and inertia permits the brush to more rapidly follow the commutator surface; second, the use of the divided brush introduces additional resistance to the circulating currents, in that that part of the circulating current must flow up through the length of one brush and down through the other brush, in order to complete its path. Such a type of holder is shown in Figure 7.

In the case of current collection by collector rings, there is not the same kind of trouble experienced as with commutators, such as individual high or low bars. Out of round collector rings give similar troubles and must be avoided to obtain good operation. Collector rings that are out of round or that have flat spots will cause brush bouncing and consequent rapid wear of brushes, with excessive dusting when metal graphite brushes are used. Such

flat spots are often caused by burning starting at any one point, due to a variation in homegenuity of material or due to a localization of current density. Once started, the flattened spot becomes accumulatively larger and larger and the accompanying sparking worse and worse. Obviously the cure for this is to grind the rings as concentric as possible. Although carbon type brushes when operated on collector rings do not have to carry any additional circulating current, they cannot be operated at any appreciably higher current densities than when operated on commutators. This is probably due to lack of cleaning action on the brush face, on account of the smooth continuous surface of the highly polished ring periphery. Where metallic graphite brushes are operated on collector rings, current densities of from 85 to 120 amperes per sq. in. of normal density are employed. Lack of humidity will cause very rapid wear of metal graphite brushes, and this condition should be very carefully watched. In some electrolytic plants employing many machines, humidity is controlled by admitting steam into the station room, when the humidity is low. It has been found experimentally that excessive brush wear will occur when the moisture content of the air in which a machine operates is less than 15 to 20% humidity at 30°C.

Operating conditions have much to do with the operation of any piece of electrical machinery. Cycle loads are, as would be expected, beneficial particularly to commutating and collector ring apparatus because the periods of light running give these rotating conductors an opportunity to cool down and polish. Conversely in the same manner, overloads are detrimental. Where commutating machines have momentary overload guarantees, such guarantees are made for the purpose of showing on the test floor of the manufacturer that the machine has a margin of overload. This condition is not to be construed as an operating overload condition. Where commutating machines must operate at frequent intervals at high overloads, a more liberally designed and more expensive machine must be purchased.

The location of a machine has very much to do with its successful operation. It should be located in a well ventilated room so that it can secure a sufficient amount of air for adequate cooling. The air provided for cooling should be free from dirt, oil and various gases. Dirt tends to bind the brushes in the holders and prohibit them from following the surface of the commutator; oil will penetrate mica and in time cause its breakdown, as well as cause failure of insulation where dirt is present by causing it to stick to the oil covered surfaces, forming a high resistance, although conducting path. Various gases will affect the surface of the commutator and keep the commutator from securing a satisfactory polish, to the detriment of successful operation.

The performance secured from a given machine is very dependent upon the maintenance given to it. Careful maintenance as a minimum consists of the following: Blowing out a machine at least once a week and wiping off the brushes at the cleaning period, where they are subjected to dust and dirt; seeing that the brush tension on all brushes is corrected from time to time, as the brush tension once set will not remain the same, due to brush wear and temperatures; renewing the brushes before they have completely worn down so as to damage the commutator, and seeing that the commutator surface is in good condition. This latter condition may mean that the commutator should be ground at least once a year. Periods of grinding of this duration is not considered abnormal maintenance, nor is it considered excessive wear of brushes if as a minimum a life of one year is secured for ordinary industrial service.

Sometimes commutators and rings have fine grooves formed on them from the action of the brush. This occurs most often where natural graphitic brushes are used as this material in itself is somewhat more abrasive than electro-graphitic brush material. This grooving is not very detrimental to operation and its occurrence does not mean that the apparatus is not performing satisfactorily. These grooves reflect light very readily and give the appearance of being much deeper than they actually are. When grooving occurs with electro-graphitic brushes, it is generally due to hard spots in the brushes or the brushes picking up copper. When the latter occurs, the copper should be removed from the face of the brush by light sanding or picking out with a knife.

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A. I. & S. E. E. Proposed Safety Regulations Necessary When Working On High Tension Lines

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Presented at Twenty-eighth A. I. & S. E. E. Convention, Pittsburgh, Pa., June 20, 1932.

Referring to the proposed A. I. & S. E. E. Safety Regulations necessary when working on high tension lines, as published in the June issue of the IRON AND STEEL ENGINEER, the following comments have been prepared.

A. 440 volts is not considered as high voltage; in most cases it is impossible to take the same precautions when working on 440 volt equipment as on equipment of 2200 volts and above. The 440 volt feeder systems in steel plants are not as elaborate as higher voltage main feeder system where there are in most cases more than one route for feeding a load. In practically all instances, 440 volt equipment must be worked hot, and for this purpose ap-

proved rubber gloves and mats which are tested at regular intervals should be used.

It should not be necessary for the department superintendent or his assistant to arrange for any outage. Any person in the department who has been given proper authority by the superintendent should be permitted to request outages. Of course these persons should be familiar with all conditions in the plant. In the case of steel plants when extreme emergencies arise, such as a man on the line, a station operator should not hesitate to clear a line if anyone notifies him of the existing conditions and can give the approximate location of the trouble.

B. Satisfactory as written.

C. It should not be necessary to request an outage in writing. Any satisfactory means of communication should be all that is required. The line foreman, general foreman, and department superintendent are not always available for supervising and checking switching. In cases where plants which are inter-connected are miles apart, this supervision and checking would be impossible.

1. Satisfactory as written except supervision and checking should be omitted.

2. Satisfactory, except for the use of locks. The application of locks by the foreman is impractical when switching points are separated by any great distance, or where there are a number of switching stations, four or five.

3. Satisfactory as written.

4. The danger sign and switching order tag might easily be combined. The name of the foreman or person or persons requesting the outage is all that is necessary on the switching order tag. Each foreman should be responsible for his own men and not hold the operator. It should not even be necessary to obtain the foreman's signature.

5. Impossible to carry out on long lines, but might be good practice on short local circuits.

6. Satisfactory as written.

D. To have the line foreman check the line against his map is impractical where any great distance is concerned.

It is not always possible to test the lines at the point of work because hot lines for checking the instrument used are not always available. However, when possible, circuits should be tested at the point of work.

E. Satisfactory, except it should not be necessary for the line foreman to supervise the removal of switching order tags and danger signs and authorize in writing the operator to energize the line. Instructions from the foreman by telephone is all that should be required.

F. The fact that the line has been reported clear of all men is sufficient, if it is not clear of equipment, relay operations will open the circuit when it is closed, thus indicating trouble.

G. In addition to warning a lineman about a hot line on the opposite side of the structure from where he is working, it is desirable to use a combination sign and barrier, which will warn him from entering the area of the hot lines.

H. and I. This is only an additional detail which does not add to safe practices, but adds to the complexity and increases chances for errors.

The above comments have been largely destructive rather than constructive. The following is a description of the form of procedure to be followed when clearing a high tension transmission line which interconnects the electric power systems of a number of steel plants.

Let us assume that this power system consists of an interconnection of five power plants through step-up transformers at each power station. That the operation of the system is under the supervision of a system power dispatcher. The central station, hereafter referred to as Station "A", has an operator on each turn who is responsible for the operation of the entire system during the absence of the system power dispatcher and therefore are called system operators. Each of the other four plants have an operator on each turn and they are called station operators.

Let us now assume that it is desired to clear one of the interconnecting lines for maintenance purposes. The person or persons desiring the outage calls either the system operator directly or requests the station operator at his plant to call the system operator. Upon being advised that a line outage is desired, the system operator obtains a switching order tag and fills it out completely, as he receives the request over the telephone. In cases where more than one group of men are going to work on the line, a switching order tag is filled out for each group. After filling out the required number of switching order tags, the system operator reads the order in detail from the tags to the person requesting the outage. This serves as a check on the request. After the request has been checked, the person or persons requesting the outage wait for the system operator to inform them that the line is clear and the system operator takes up the following procedure to clear the line.

1. The system operator calls each of the station operators separately and reads to each station operator, from the switching order tags, the detailed request for the outage.

2. Each station operator makes out switching order tags which are duplicates of those made out by the system operator and repeats the order from the tag, assuring the system operator that the station operator has received the order correctly in every detail. The system operator then requests the station operator to open his high tension oil circuit breaker and hang the tags on the control switch while the system operator holds the telephone connection. After the station operator reports the breaker open, the system operator requests the station operator to open all disconnect switches and report to him.

3. The system operator, after the high tension oil circuit breakers have been opened at all the other plants, opens the low tension oil circuit breaker at Station "A" on the transformer which is feeding the line for which the outage has been requested. By opening the low tension breaker and keeping the high tension breaker closed, the Station "A" voltmeter connected to the high tension line indicates whether or not there is voltage on the line from any source. When the system operator is assured there is no voltage on the line, he opens the high tension oil circuit breaker and all disconnect switches and waits for the call from each of the four stations, notifying him that the line is disconnected.

4. After all four stations have reported the line

clear and Station "A" has disconnected the line and tagged it, the line is supposedly dead. To make a further check, the system operator goes to the Station "A" outdoor transformer station and closes the line short circuiting and grounding gang operated disconnect switch, which has provisions for locking in this position.

5. The system operator then having short circuited and grounded the line, reports to the persons who originally requested the outage, that the line is clear.

6. The group or groups of men who are going to work on the line having been assured that the line is clear, are now ready to take the necessary precautions before they begin work. Each group of men is provided with two sets of short circuiting and grounding clamps or chains, one of which must be properly attached to the line on either side of where the group of men are working. After the two short circuiting and grounding clamps or chains have been applied, the men are ready to go to work.

After the work on the line has been completed, each group working on the line removes their short circuiting and grounding chains or clamps, and the leader of each group reports individually to the system operator or their station operator, that they have finished work and are clear. The system operator, upon being informed as group finished work on the line and reports clear, removes the switching order tag from the control switch. After the last tag is removed, the system operator knows that everybody is clear and the line can be restored to service. This is done as follows:

1. The system operator opens the line short circuiting and grounding switch in the outdoor transformer station at Station "A".

2. The system operator calls each station operator separately and notifies him that the men are clear of the line, to remove the tag, make the line available for service, and report to the system operator.

3. After having received reports from all the station operators that the line is available for service, the station designated to energize the line is instructed to do so and report to the system operator. The other four plants in order are instructed to close in on the line and report to the system operator. The line is thus energized and all stations are on.

The safety regulations as discussed up to this point have been merely in connection with the procedure necessary when working on high tension lines, or in other words, the assumption has been made that satisfactory equipment has been installed in these power houses, switching stations, and on the transmission lines which when operated, will make the line safe for men to work. As a suggestion, should not the A. I. & S. E. E. include in their safety code, regulations for the design and construction of power houses, switching stations and transmission lines, in so far as the safe operation and maintenance of equipment and the safe working of men are concerned?

Probably one of the most important factors in connection with the safe operation of any power system is that of communication. It is essential that satisfactory means of communication be maintained between the system operator and the outlying power station operators at all times. This is especially true during line and station outages caused by lightning and other weather conditions which may affect a communicating system. This problem has been solved on one power system by the use of three separate and distinct telephone systems, namely, a private mill automatic telephone system, the Bell System, and an independent telephone system for the power system use only. The independent telephone system uses magneto ringing, and is thus immune from the effects of outage of any generating or converting equipment.

Another feature of these telephone systems is that to as great an extent as possible, an effort has been made to isolate the circuits from one another. In only approximately 10% of the total length of right-of-way was it impossible to separate the circuits by using different cables. The Bell circuits of course are carried in their own cables, the intermill automatic telephone circuits are in the regular mill telephone cables, and the independent telephone circuits are in the telemetering cables. Thus only under very extraordinary circumstances would it be possible to have all three telephone circuits out of service simultaneously.

When men are working on transmission line towers supporting more than one circuit, it is very essential that the circuits be clearly identified by markers permanently attached to the tower. In line with this same thought, it is also very helpful if the circuit phases are marked. Switching stations and power houses should have all equipment marked both as to the circuit and phase designation.

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Fuel Economy Under Curtailed Operating Conditions

By H. DOBRIN
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Presented before Combustion Engineering Division of the A. I. & S. E. E. at the Twenty-eighth Convention in Pittsburgh, June 22, 1932.

A few years ago, when production schedules were high and operations were running at full tilt, the concern of the fuel departments in the steel works was mainly with improved quality. With the increasing demand for quality it was hardly possible to emphasize too strongly the question of fuel economy. While economy of fuel used has always been incidental and quality the foremost object, a reversal in general business conditions has caused managements to be very insistent on the factor of fuel economy. Of course, it was very necessary to first establish the primary importance of quality heating

over that of economical heating at the expense of quality.

The extent to which some of the more aggressive concerns have succeeded in their insistence on greater fuel economy will be brought out in this paper.

The fuels represented in the experience of the various plants to be mentioned here consist of fuel oil, tar, producer gas, natural gas and coke oven gas. Some of the producer gas figures also include 25% of coke braize and some screened coke. The values here mentioned will be in terms of millions of B.T.U. For all those who are not accustomed to thinking in terms of B.T.U.'s, it may be explained that they are derived as follows:

Fuel oil or tar—7 gallons is 1,000,000 B.T.U.

Producer gas—95 pounds of coal is 1,000,000 B.T.U.

(This is net and allows for conversion loss from coal to gas delivered at the furnace.)

Natural gas—1000 cubic feet is 1,000,000 B.T.U.

Coke oven gas—2,000 cubic feet is 1,000,000 B.T.U.

One plant where means for accurate determination of fuel used per ton for open hearth melting have been very highly developed, and all kinds of facilities were handy for the proper measurement of the gas, had the following interesting experience:

During 1926, the average monthly tonnage being 30,000 tons, the fuel used was 6,874,000 B.T.U per ton of steel melted.

In 1927, with an average of 26,000 tons per month, the fuel was 6,920,000 B.T.U.

In 1928, with an average monthly production of 39,000 tons, the fuel was 6,802,000 B.T.U.

In 1929, with an average of 41,000 tons per month, the fuel was 7,014,000 B.T.U.

In 1930, with a drop in production to only 19,000 tons per month average, the fuel was 6,784,000 B. T.U.

In 1931, with an average tonnage of 21,000 per month, the fuel was 5,567,000 B. T. U.

Most of the improvements such as pressure fans and temperature indicators for the checker temperatures had all been installed during 1928 and 1929, but as is noticed in these figures, the real improvements did not occur until 1930 and 1931. The total fuel here used per ton also included the extra fuel used due to the necessity of shutting down and bringing up furnaces, one involuntarily caused by uncertain and declining operating schedules. As is generally known, this has been a condition from which hardly anyone has been exempt. For five months during 1930, the average fuel which had to be charged to the involuntary shutting down and bringing up of furnaces was 537,000 B.T.U. per ton of ingots. All this fuel was included in the total of 6,784,000 B. T. U. for the year 1930. This total also included all auxiliaries in the open hearth used for ladles, mixer, etc.

The figure above mentioned of 5,567,000 B.T.U. for the year 1931 also included involuntary shutdowns and warm-ups of furnaces, as well as auxiliaries for ladles, etc.

These improvements were brought about during 1930 and 1931 by changing uptakes, balancing drafts, reducing excessive drafts and also by the finding of certain slopes in the furnace ports which, for those particular furnaces, happened to be ideally suitable. Some of these slopes cannot be standardized and have to be found for each individual furnace, but it shows that this happy combination, if finally found, will consistently bring about more economical results. Incidentally, in this particular shop, in the measure that the fuel figure was reduced, the furnace tons per hour have been increased.

During the years 1930 and 1931 the reduced fuel figures were all the more impressive to the management since in previous years this shop had always had available some 25% of hot metal; but during 1930 and 1931 there were many months when heats had to be produced with cold pig. Later, when some of these fuel practices were more painstakingly analyzed and expected fuel to be used standardized, there was an understanding that whenever cold pig was used it was allowable to charge about 800,000 B. T. U. more per ton of steel thus made than when hot metal was available. Only for the fact that some of these important improvements were carried out, the management, having had previous experience to check against, would ordinarily have raised no protest if the fuel practice with cold pig had been as good as it was with hot metal.

In the plant under discussion economies in the fuel used were general, and in many departments showed a consistent reduction as against heavier schedules, and in a good many cases, the rise of fuel used was stemmed and the fuel figure held in check.

For instance, in sheet normalizing the following figures may be mentioned: During the year 1928, the average monthly tonnage was 11,500 tons of sheets normalized. The fuel used was 3,860,000 B.T.U. For the year 1929, with a monthly tonnage of 15,360, which was a considerable increase over the 1928 tonnage, nevertheless, the fuel was 4,080,000 B.T.U. per ton. In 1930, with a decline to only 9,350 tons per month, the average fuel per ton in gas was 2,925,000 B.T.U. In 1931, with 11,000 tons per month, the fuel was 2,518,000 B.T.U. Comparing this with tonnage which was almost identical for the year 1928, there was here a reduction of practically 1,350,000 B.T.U. per ton. In January, 1932, with production of 11,000 tons, there was a further reduction to 2,330,000 B.T.U. With fuel at 25 cents per million B.T.U., it can be easily calculated that the saving in this one department alone per month of 1932 experience as against that of 1928 practice, was equal to $3,575 per month. This was brought about by the consistent checking up on furnace atmospheres, and careful upkeep of furnace equipment.

Something similar occurred for fuel used for deoxidizing or bright annealing. For the 192,000 tons so treated for the year 1929, the average gas was 730,000 B.T.U. per ton. For the 89,000 tons so treated in 1930, it averaged 715,000 B.T.U., and for the 73,000 tons so treated for the year 1931, it averaged 365,000 B.T.U. per ton. This was brought about by the careful attention given to gas pressures and heating cycles.

Some people pay around 40 cents per million B.T.U. for natural gas, which would make a difference of practically 14 cents per ton, or $10,220 for the year on this item alone.

The open hearth savings in this particular plant, on the difference between 1929 and 1931 practice, of 1,457,000 B.T.U., and at an average of 25 cents per

1,000,000 B.T.U., on the annual tonnage for 1931 of over 250,000 tons at 36½ cents, is $91,250. This saving over the 1929 total of over 490,000 tons would have amounted to $179,850.

In another plant, the total melting cost in fuel in the open hearth for 1928, for an average of 34,000 tons per month, or 408,000 tons per year, amounted to 8,200,000 B.T.U. per ton. This included fuel used for ladle heating and other auxiliaries; while the melting alone, without any auxiliaries, amounted to 7,850,000 B.T.U. The average for 1929 for practically the same tonnage, about 410,000 tons for that year, amounted to 7,090,000 B. T. U. per ton for fuel used in this shop for melting and other auxiliaries.

In 1930, the tonnage dropped to 305,000 tons and the fuel amounted to 6,030,000 B.T.U. per ton of steel melted.

For 1931, with a still further decline in tonnage to only 240,000 tons, it averaged 5,400,000 B.T.U. The latter figure included auxiliaries and shut downs due entirely to business conditions. It also included months when only cold pig had to be used as against the practice of using about 25% of hot metal during the years of heavy production schedules. The extent of the item of charges incident to shut downs may be realized upon disclosure that there was an average of close to 400,000 B. T. U. per ton of annual ingot production during 1931 which had to be charged to this item alone. Omitting this item, the actual melting, including auxiliaries, was really done for 5,000,000 B.T.U. on the entire year's production.

Even with the limited 1931 production of 240,000 tons and a fuel reduction of 1,690,000 B.T.U. over the 1929 fuel practice, and at 25 cents per million B.T.U., this saving amounted to 42¼ cents per ton or $101,400 for the year. On the same basis it amounted to 15¾ cents over the 1930 fuel practice per ton, or $37,800 greater saving for the year. Had they melted the steel of 1929 for their 1931 fuel in B.T.U., the saving then would have been over $173,000.

In still another plant, natural gas being used as a fuel, total production in the open hearth for the year 1929 was 420,000 tons, and the fuel used was 6,640,000 B.T.U. per ton. This included auxiliaries. In 1930 there was a sharp decline in business and the total tonnage dropped to 168,000 tons for the year. Nevertheless, the fuel figure for this year for melting steel averaged 5,880,000 B.T.U. per ton. This also included ladle heating and other auxiliaries.

For the year 1931, with only 130,000 tons production, the fuel averaged 5,640,000 B.T.U. This included shut-downs due to the enforced taking off and bringing up of furnaces. For a period of eight months, the item chargeable to shut downs alone averaged 585,000 B.T.U. for each ton of production in this shop. So the actual melting including auxiliaries but without the shut down charges, was accomplished for a figure of a little more than 5,000,000 B. T. U. per ton. There was, therefore, an even 1,000,000 B. T. U. reduced from the 1929 figure, yet the 1931 production was only 32.3 per cent of that of 1929. Taking out the 585,000 B.T.U. which was the extra shut down cost not experienced in 1929, there was a net reduction in this shop of over 1,500,000 B.T.U. per ton of steel melted.

In the same shop the following experience occurred in sheet normalizing. The average for 1929 was 19,000 tons per month at a fuel of 3,180,000 B.T.U. per ton. Average production for 1930 was only 5,000 tons per month, but the fuel was reduced to 2,897,600 B. T. U. per ton. For 1931, the production still further declined to only 4,600 tons per month, yet the fuel was 2,816,000 B. T. U. During January, 1931, with a tonnage of only 3,900 tons, the fuel was still further reduced to only 2,390,000 B.T.U. per ton.

It is easily understood that when furnaces have to be lighted up and brought up to heat for only a run of a day or two here and there, that it is to be expected that the average fuel per ton will mount in view of the small tonnage produced for the amount of total heat which has to be used to light up a furnace from cold. These charges for heating up were not separately kept but were all included in the total; the accounting charged the total fuel used in this shop and divided it by the production realized.

Similarly for box annealing of sheets which for 1929 averaged 9,900 tons, the fuel used was 1,920,000 B.T.U. In 1931, with an average of less than half, or a production of 3,400 tons per month, the fuel was reduced to 1,750,000 B.T.U. per ton.

In another plant, with steadily declining schedules, it was found possible to hold the fuel practice fairly in check, and in some cases, with greatly reduced tonnages, there was a reduction in the fuel used. Here the average production in the soaking pits for 1929 was over 110,000 tons per month. The fuel used was equal to 778,000 B.T.U. per ton or about 74 pounds of coal. In 1930, with a decline in production to 88,000 tons average per month, the fuel was reduced to 755,000 B.T.U. per ton. In 1931, with a still further decline to only 59,000 tons average per month, and with some soaking pits operating only one turn, and kept under heat but idle the other two turns, the fuel rose to 949,000 B.T.U. per ton. This, as will be explained, must be considered very good practice.

In order to check up on the possible losses resulting from the idle time during which soaking pits are kept under heat when a mill is not in operation, it was developed that for a block of 4 pits size 6′x9′, there was a theoretical radiation loss per block of 2,770,000 B.T.U. per hour and for 14 idle hours it amounts to 38,780,000 B.T.U. With an average of three heats to the turn, 80 tons to the heat, a simple calculation will show that the fuel theoretically radiated between turns amounts to 161,000 B.T.U. for each ton during the production turn. But it amounts to much more, as the calculation only shows theoretical radiation of heat units, and the fuel therefore would have had to be utilized 100% efficient in order to have amounted to only 161,000 B.T.U. for each ton produced. The basis of the calculation was for a temperature of 2200°F.

In the same plant, the fuel per ton for welding pipe had been 4,250,000 B. T. U. for the year 1930. In 1931, with only half the production it rose to an average of 4,880,000 B.T.U. Those familiar with work of this kind know that this is an achievement, in view of the fact that a welding furnace is not

easily let down and that the furnaces are kept under heat between idle turns and also during an interrupted or low operating schedule.

In this particular plant the standard for by-product gas used had been that of 500 B.T.U. per cubic foot. During 1931 the gas was of a much lower heat value due to an enforced longer coking period. The gas quality was only from 460 to 470 B.T.U. But in the accounting system no downward revision or allowance was made for the lower heat value of the gas. The figures mentioned represented gas values as of 500 B.T.U. per cubic foot, else more substantial economies would have been shown.

In still another mill, with producer gas as fuel, where merchant bar was rolled from cold billets and on old furnaces, the production on one mill for 1929 averaged 13,700 tons per month at a practice of 2,620,000 B.T.U. per ton.

In 1931, with a production of only 5,400 tons average per month, the fuel was 2,523,000 cubic feet per ton.

An adjacent mill also rolling merchant bar from cold billets at a 1929 monthly production of 12,100 tons, used 2,008,000 B.T.U. per ton.

In 1931, with a decline in the monthly production to only 4,060 tons, the fuel used was 2,045,000 B.T.U. per ton.

There are many more such instances which could be cited but which would serve no useful purpose other than to emphasize the points intended to be brought out in this paper.

Some of these results were brought about by a very aggressive organization policy in utilizing to the utmost the function and the services of the combustion and metallurgical departments. Some attention had to be paid to infiltration of undesired air through all kinds of openings, cracks and crevices in the checkers and other parts of the furnace. In addition to finding more successful furnace lines, it has also been of great importance to pay particular attention to the manipulation of dampers and the maintenance of certain balanced draft conditions in furnaces.

In some plants particular attention had to be paid to the reduction of the excess oxygen in furnaces to a minimum. In some cases where there have been all kinds of furnace controls, more attention has been paid to the extracting of the best advantages that there is latent in such controls. In the absence of elaborate control equipment, more attention has been paid to the resultant flue gases which have been continually analyzed so as to be sure that the proper combustion was taking place in the furnaces. We have found, for instance, that free oxygen at high temperature in most metallurgical furnaces is a foe to quality, as well as to economy.

The proper use of a damper in a metallurgical furnace is an unknown factor in many departments. For years many organizations have allowed their open hearth operators to run with a wide open damper because that was the current practice in the industry. The first step in the new order of things is to make it comparatively easy to change damper settings, and from then on it will be much easier to sell this idea to the furnace man. It has been the experience of many open hearth shops that they can do with less than half the draft that they thought necessary five or six years ago. In fact, some of the very best practice is being achieved while there is a slight positive pressure being maintained in the uptake, and simultaneously a suction in the downtake of a regenerative furnace.

The same program, if applied in the soaking pit department, will also result in success. Insulate the outside of the checkers, close all avenues for the infiltration of the unwelcome cold air which robs the furnace of heat and does not improve the quality of the heating.

Some of the improvements which were cited in the above paper have resulted without any extensive expenditures for new apparatus or for rebuilding the furnaces, but were accomplished in the ordinary course of watching for leaks and of stopping them. It is comparatively easy to locate leaks; the art is not only in stopping them but in gaining such mastery over them that these leaks which cost many dollars, will be permanently stopped up.

The data in this paper represents the experience of organizations who have long recognized the importance and value of staff forces who have been well trained and are qualified to cope with metallurgical heating problems. In a pinch, with the inevitable large losses sustained by the entire steel industry, the time, energy and expense of developing a well trained combustion department served to greatly minimize these losses, which would have been still greater had not the combustion staffs used their best energies to lower fuel costs.

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The Commercial Aspects of Power Factor

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By J. F. GASKILL
Manager, Industrial Sales Dept., Philadelphia Electric Company, Philadelphia, Pa.

Presented before Philadelphia Section of A. I. & S. E. E., March, 1932.

About twelve years ago the question of the effect of power factor on the cost of service became very active among all the utilities on account of the increasing importance of induction motor loads. At this time the Philadelphia Electric Company conducted a series of tests in order to obtain some actual operating data to supplement and confirm the theoretical analyses of the effect of inductive loads.

These tests included:

(1) A continuous running record—these records were tabulated in thirty minute intervals, showing the kilowatt-hours and the reactive Kva. hours consumed for each interval over the entire period of the test; and

(2) Tests on a feeder and transformers supplying one industrial customer in which variable cor-

rection was obtainable—showing the loads, line loss, and voltage drop at the sub-station and at the customer's plant.

Our company has just completed another series of tests in order to bring our knowledge of this problem up-to-date and to determine if advances in the metering art would permit some permanent form of installation for power factor measurement. Unfortunately, the final results of this study are not available as yet, although I delayed writing this paper as long as possible in the hope that I might be able to include them. Up to the present however, the conclusions, insofar as loads are concerned, completely confirm the results of the original study, which were:

1—that in consumers' plants the maximum kva demand frequently but not necessarily occurs at the same time as the maximum kw. demand;

2—that, following from 1, the power factor in ordinary industrial establishments fluctuates in such a manner with the load cycle that a reduced kw. demand may mean an increased kva. demand.

3—that the effect of low power factor is to restrict the generating, sub-station and line capacity available for the generation and distribution of energy, and to produce poor voltage regulation from the generating station to consumer's service.

In order to visualize for you the importance of power factor from the standpoint of the utility, it has been estimated that while the costs to serve low power factor loads increase in the order of from 10 to 12% when power factor drops from unity to 80% power factor, the rate of increase is much greater between 80 and 60% power factor. The problem, from the standpoint of the utility, naturally resolves itself into the discovery and application of the best method of obtaining correction because, obviously, the need for measurement and charge disappears as soon as the cause of the problem is eliminated. This fact, in my personal opinion and with which, of course, many differ, places the measurement and billing for power factor in a somewhat different category than that for the measurement and billing of the kilowatts of demand and kilowatt-hours of energy consumed. Assuming that all customers would operate corrective equipment once it was installed, there would be no need for measurement except as a check on operation of corrective equipment, nor would there need to be any statement of charge for power factor on the bill. It is possible that an assumption of this character is illogical in the face of the known characteristics of human nature.

If, however, we keep these differences between the measurement of billing for energy and the billing for a characteristic of electricity (which has never been satisfactorily defined in words of one syllable) in mind, suppose we turn to a consideration of some of the methods of metering which have been adopted by a number of the utility companies in the attempt to induce customers to correct their power factor.

1—The conclusion to which anyone would naturally turn as ideal would be the adoption of a kva. method of billing. This would immediately charge the customer for the total capacity required by him from the system, and, without any additional testing or measurement, would automatically reduce his demand charge as he reduced his total kva. demand by means of corrective apparatus.

Very definite factors of a practical nature have delayed the universal adoption of this method of measurement to determine the demand element of billing. They are, first, the somewhat complicated and very expensive instrument necessary to obtain adequate, continuous kva. demand measurements, and, second, the difficulty of attempting to establish a cost for a unit which is in itself a combination of both kilowatts and re-active kva.

Notwithstanding this, 17 out of 54 utilities questioned on this subject in our recent survey are billing on a maximum kva. demand. Unfortunately, I am unable to report as to the efficacy of this method of billing in inducing power factor correction by power customers.

I believe that you will all agree that the kva. demand measurement would be ideal if the two objections of metering and unit cost could be, and as they very probably will be answered. As things stand at present I must confess that while other considerations might change my thought, I do not at present warm up to the idea of placing a large number of very expensive instruments in service whose function would be merely to check the customer's operation to assure us that the corrective apparatus which he had installed was functioning properly. Owing to the complication of this problem of measurement, many different practices exist among the various utilities who are enforcing power factor clauses in their tariffs, with the result that it is almost impossible to state at this time just what will be the ultimate outcome.

It is certain that the average power factor over the customer's normal operating load cycle approximates very closely the power factor at the time of maximum kw. demand. This statement, of course, must be modified to consider the case where abnormal operating conditions obtain in the customer's plant. Here again continuous measurement leads into complications because of the fact that many customers elect to install group correction at the service from the standpoint of economy, or to install large synchronous motors on loads which are favorable to such applications. This situation requires, I believe, a certain amount of flexibility in handling, as emergency conditions in the customer's plant might cause the elimination of corrective equipment over short periods of time.

2—The use of periodic tests at the time of normal loading, defining such normal loading as operation within the minimum and maximum limits laid down in the contract, if such exist, or at a certain percentage of the contracted load, avoid the complications of expense and abnormal plant conditions inherent in continuous measurement. This is the method which has been used largely over the Philadelphia Electric Company System. It also has certain objectionable features which are:

1—The customer's corrective equipment may cease to function without his knowledge, thereby imposing a continuous low power factor load which might endanger service, transformers and affect other customer's service through poor regulation.

2—It offers opportunity for abuse through load manipulation at the time of the test.

3—There is a possibility that some individuals

might purchase corrective equipment to be operated only at the time of the test.

All these difficulties can be practically controlled by the periodicity of testing.

Admitting the possibility of all these things happening, it has been my experience, over some ten years of contact with this problem, that by far the majority of the customers who have connected 110,000 kva. of corrective equipment on our lines during that period have not taken advantage of the obvious loopholes in this method of measurement. Frankly, I do not believe that there are many men in business who will destroy the usefulness of a method of procedure which is obviously adopted for their benefit in order to give them the advantage of flexibility in applying the power factor clause.

3—Continuous measurement by means of re-active component meters whether ratcheted or not, with the idea of establishing an average monthly power factor for billing purposes, produces a value which is very much less than the power factor at the time of normal operation or at the time of maximum demand where no corrective equipment is installed, and a value which is greater than the normal operation power factor, etc., where customers have corrective equipment.

I believe that we have discussed the problem from the utility standpoint sufficiently to permit you to see that the problem is extremely complicated from all angles and that such steps as have been taken to solve the problem have not as yet resolved themselves into definite acceptance of any one standard form of procedure, where the power industry in general is concerned. Perhaps it might be best to leave with you the thought that insofar as our company is concerned its policy has been to work toward a method of measurement which would be most equitable for both customer and utility, without attempting to set up a procedure which failed to consider the varying problems of different customers. We have never considered power factor as a desirable source of revenue, feeling that the problem itself disappears after corrective equipment is in operation. It is quite possible that the present methods of measurement in use by our company may be modified to obtain a basis for this charge. If so, I believe that you can feel assured that no matter what method of measurement may be adopted, we will always consider the charge for power factor as an inducement to correction rather than a source of revenue.

In considering the elements of industrial load which bring about low power factor we must remember that practically the entire development of the application of electricity to industry has been based upon the use of alternating current, for reasons which have been so often discussed that it will be unnecessary for us to consider them in this paper. This basic development has necessarily been accompanied by the use of inductive apparatus which, in turn, has led to the problem of power factor. Owing to the corrective effect of electrostatic capacity in long transmission lines, the difficulties which have been introduced by inductive loading have their maximum effect in the distribution areas of congested localities. The amount of magnetizing or re-active kilovolt-amperes required by inductive equipment varies with the design and size of non-rotating equipment and, assuming constant voltage and frequency, with the design, speed and size of motors. The re-active kilovolt-amperes are, neglecting the small effect due to leakage magnetizing current which increases with the increase in load, almost constant from no load to full load.

It will be seen from these considerations that in the application of electrical equipment to industrial loads that the selection of the proper design and size of stationary equipment (such as transformers, etc.) and the proper size, design and speed of rotating equipment (such as motors, etc.) is of paramount importance.

I believe that while this fact is better known and considered today than it was ten years ago, it is still too often disregarded in favor of an unnecessarily large safety factor between the capacity of the equipment installed and the load which it will have to carry. The manufacturers have made available equipment to cover all practical ranges of application, but too frequently motors have been and are selected whose characteristics do not fit them for the work which they are supposed to do, with a consequent decrease in efficiency as well as a resultant poor power factor. For example, in the installation of a motor to handle the shock loading of a punch press, I have in mind a particular case where a 10 horsepower motor, low slip, was first applied. This motor with its close speed regulation, which adapts it admirably to constant speed loads, did not permit the fly wheel of the punch press to give up its energy during the peak demand of the equipment, with the result that the test of the motor showed that between 5 and 6 horsepower were actually required to operate the machine as set up. The application of a 5 horsepower, high slip motor, which permitted the utilization of the fly wheel energy during the peak load showed, under test, the use of between 4 and 5 horsepower to accomplish the identical result.

Here, of course, with the proper application, more efficient loading and a better power factor were obtained, notwithstanding the inherently lower power factor of the high slip motor under full load operation. Incidentally, the plant in which this application was made showed that around 64 kva. of corrective equipment would have been required to correct the power factor without this and several other changes of a similar nature. After the changes were made, the total necessary correction to reach the desired value of power factor was found to be only 30 kva. I believe this is an excellent illustration of the value of considering the characteristics of loading in the selection of the size and design of motors.

We have frequently noted a tendency, on the part of many customers who are intending to purchase our primary service, to install transformer capacity much larger than their immediate and near future requirements. It might be well to point out at this time that this practice should always be modified by a consideration of the effect on the plant power factor as compared to the cost of increasing the transformer capacity at some later date.

After all possible consideration has been given to the problem and the proper equipment has been applied to the various plant operations, there are many things beyond the control of the designer and operator of the equipment which affect the power

factor. Probably the most important of these is intermittent loading, either through long intervals such as air compressor operation, or through short intervals such as the operation of hosiery machines where the average loading is made up of a series of sharp peaks, spaced closely together. It must be remembered in loads of this character, which are very frequent in the industry, that since the re-active component or magnetizing current is fairly constant from no load to full load, the wide variations in the load component produces a low resultant power factor.

Motors designed without placing emphasis on the value of high power factor have also been the cause of considerable difficulty on account of disregard of this important factor in motor operation. Almost all manufacturers have produced lines of motors in recent years which are a great improvement over the discontinued lines, and I would, therefore, suggest that in surveying plants with the idea of improving power factor, motors of ancient vintage be tested carefully to be sure that a more modern type could not properly replace it.

In considering the correction of power factor, after it has been determined that the proper motor applications and transformer capacities, etc., are in use, the available practical equipment may be divided into four classes:

1—Synchronous Condensers

This is essentially a rotating machine built to operate at leading power factor to supply the magnetizing current required, and is economical only in very large sizes and, as such, has a limited application in the industrial field.

2—Synchronous Motors

This is a piece of rotating equipment built to operate at unity or leading power factor in order to eliminate the re-active kva. required for a particular application and, if designed for leading power factor, to perform this function and also to supply leading current to improve the power factor of the remainder of the plant. This apparatus represents the cheapest method of correction provided large unit applications are available (approximately in excess of 50 kw.), and is generally considered in competition with or supplementary to the group static condensers and the small unit static condenser for application at the motor terminals

This type of motor should be carefully considered in motorizing any proposed plant, as modern design has widened its application to such an extent that it can be used on almost any kind of load.

3—The Static Condenser

(a) Group application at the service

In this field of application the static condenser should be used only after assurance has been reached that little saving can be obtained by means of correction at the source, either through synchronous motors or small static condensers. This equipment is most economical at 2300 volts and, therefore, requires step-up or step-down transformers if the service voltage varies from that value, thereby decreasing the economy of the installation for voltages above or below 2300.

(b) The Small Secondary Voltage Static Condenser for connection to the motor terminals. This equipment, while relatively expensive per kva. of capacity, offers the additional advantage of the possibility of saving plant line losses and improving regulation at the motor terminals.

4—Unity Power Factor Load

The addition of any unity power factor load results in an improvement of power factor, and advantage may frequently be taken of this fact by the use of synchronous converters and unity power factor synchronous motors.

From the standpoint of the consumer, power factor has the same effect on the capacity of lines, transformers and receiving equipment as it does upon the generating, transmission, sub-station and distribution capacity of the central station. Line losses and regulation become a really serious factor in industrial plants where the distribution distances are fairly long and where the resultant plant power factor is considerably below that on which the capacity of feeders was estimated. In old plants which are approaching the problem of power factor, we have frequently found that excess copper has originally been installed in the feeders, either on account of extraordinary safety factor or in an original attempt to avoid some of the diffificulties due to low power factor.

In these cases any attempt to correct at the source of the power factor condition would be, in a sense, a duplication of investment because the trouble inherent in low power factor has been largely cared for by the investment in excess feeder copper. In other cases where the installed feeder capacity is considerably below that necessary for good operation under the low power factor condition, the source correction is strongly indicated. So we see that in considering the problem of correction from the standpoint of the consumer a careful analysis should be made in order to bring to light various factors in the installation which will serve as a guide to judgment in determing the kind of correction to be used. It is not difficult to visualize a problem which, upon analysis would indicate the installation of a synchronous motor (one form of source correction) on a part of the load, individual static condensers at the motor terminals for another part of the load, group static condensers for building or department correction and, finally, another group of static conddensers at the service to obtain the final amount of correction necessary to reach the desired value of power factor.

Source correction is profitable and applicable in general only on those motors which are continuously in operation, so as to give the maximum possible return on the somewhat higher investment of individual static condenser correction. Advantage can be taken of the diversity on intermittently loaded motors by means of the departmental or building group correction referred to, and when the maximum amount of correction which can be profitably obtained at the source and at building or departmental locations has been realized, the remaining correction necessary can be obtained by group correction at the service, at which point the diversity of loading of the entire plant will have its maximum favorable effect. I would say that as a general rule group correction at the service should not be utilized until it has been determined that the saving in line losses and improvement in regulation by source and departmental correction is a negligible factor. We

have frequently found that the savings, through source correction, as will be shown by examples later on in this paper, have more than equalled the reduction in the bill due to increase in the power factor at the service.

In addition to the actual savings due to line losses which, of course, increase as the square of the current which, in turn, increases directly with the decrease in power factor, the problem in regulation and its effect on the speed of the machinery is very important, particularly in cases of extremely low power factor. This condition frequently causes non-uniformity of product as well as an actual reduction in the units produced per hour, and is so important that its consideration should never be neglected in any study directed toward improvement of plant power factor.

An intersting example of some of the facts stated in our general discussion is offered by a hosiery mill, whose original installation consisted of a number of 1 and 1½ horsepower motors and one or two of from 2 to 3 horsepower. In the original design of the plant layout the feeders had evidently been installed on the assumption of a power factor in the order of 80% and were, therefore, entirely inadequate when the load eventually developed a power factor of 33⅓%. As you may imagine, conditions were deplorable—compound was running from the cable, connections were hot, poor regulation vitally affected the speed of the motors and production was very unsatisfactory. Correction at the source in the form of small static condensers was installed. The heating of feeders and connections disappeared, regulation improved and, in addition to the saving due to the elimination of power factor from the billing, the following improvement in operation was noted:

Power Factor Correction in Hosiery Plant

	P. F.	Kw. Demand Billed	Kw-Hr. Light	Kw-Hr. Power	Total Bill	Doz. Pairs Hose	Kw-hr per Doz. Prs. Hose	Cents per Doz. Pairs Hose
			(Before Correction)					
Average over four months	33.5	61.0	1,488	5,705	$368.50*	7,408	0.86	4.95*
			(After Correction)					
Average over three months	80	33.2	426	4,203	$250.00	7,879	0.588	3.17
Per cent reduction.....		**15.2		**26.4	32.20		31.6	34.0

*The cost includes the cost of light, which is greater in the period before correction because of the season. With an allowance of even $50 for light the saving is still in the order of 20 per cent.
**Excluding light.

Another very interesting problem in correction was successfully solved in a plant devoted to the manufacture of industrial plant equipment. An increase in transformer capacity, which was unused, resulted in a power factor of 69%. By the elimination of a certain amount of unused transformer capacity and rebuilding a 115 H. P. unity power factor synchronous motor to operate at 80% lead, a power factor of 97.1% was obtained which completely eliminated the billing for power factor and probably resulted in a certain saving in line losses, the amount of which is not available because the complete changes involved in this work only cost in the neighborhood of between $400 and $800, which represented a very attractive pay-out through the savings in billing alone.

In another installation the use of group static condensers was practically mandatory on account of the fact that the plant involved was a loft building, with numerous tenants and a somewhat frequent change of occupancy. This condition, of course, practically prohibited the installation of source correction as the owner had no control over the equipment installed by the tenants. A group condenser was installed and resulted in a power factor correction from 72.6% to 93.2%. This correction resulted in an actual annual saving of approximately $400, at a complete installed cost of $1050 for the equipment.

I might go on at great length in detailing instances of the application of the various types of corrective equipment, but I believe that these should be sufficient to emphasize the thoughts which have brought out in the general discussion of the problem.

In conclusion, I wish to assure you that we will be only too glad at any time to assist any of you in analyzing plant operation with relation to this or any other problem about which our many years of experience may have permitted us to accumulate considerable information.

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DISCUSSION

Discussed by

F. O. Schnure, Electrical Supt., Bethlehem Steel Company, Sparrows Point, Md.

W. H. Burr, Electrical Supt., Lukens Steel Company, Coatesville, Pa.

J. F. Gaskill, Manager, Industrial Sales Department, Philadelphia Electric Company, Philadelphia, Pa.

N. C. Bye, Chief Engineer, Henry L. Disston & Sons Inc., Tacony, Philadelphia, Pa.

R. F. Gale, Plant Engineer, The Midvale Company, Nicetown, Philadelphia, Pa.

F. F. Herrmann, Chief Electrician, Helwig Silk Dyeing Company, Philadelphia, Pa.

F. O. Schnure: The question of power factor is very important, particularly in small industrial establishments such as pointed out in the paper this evening, and it is very easy to see that the power companies must take steps either to put a penalty on poor power factor and educate the industrial management in that way, or educate the industrial application engineer himself. These utilities are always very ready to penalize us poor fellows who buy power, and I think those of us who install correcting equipment ought to have a bonus. In other words, if it is right to penalize, it is also in order to give a bonus for correction.

The speaker talks a language a little different from the one we have been brought up on, especially in the iron and steel plants. Often our main idea is to get a motor that is somewhat larger than necessary, because we know many times in its life it is going to be called on to do twice as much work as anticipated, or additional duties be put on to cause extra load. This over motorization is what plays havoc with power factor.

In regard to putting on synchronous motors for power factor correction there is one advantage we have in a steel mill that the small industrial plants

do not have, and that is, we usually use two classes of power—direct current for the cranes, and variable speed auxiliaries and alternating current on pumps and constant speed equipment, so that if we install synchronous motor generator sets for our direct current power conversion, we have a chance to correct our poor power factor.

At eight or ten mill groups we usually have about 1000 KW D.C. and the same amount of A.C. load so that we can use synchronous motor generator sets and correct our power factor at the source. Again, in our plant and a great many of the other large steel plants, gas engine driven generators are operated. These gas engines are usually supplied with over capacity generators, which can be used for power factor correction. And it so happens that we are able to maintain unity power factor on fairly heavy loads where part is purchased and the majority generated. However, we are only able to do that because years ago we started to look into this question of power factor correction. Synchronous motor driven generator sets were installed in preference to rotary converters, and five or six years ago, when we were contemplating a new mill which required motors in the order of 4,000, 5,000 or 6,000 H.P., where our practice formerly, was to install induction motors, large synchronous motor application had reached that point where they could be applied.

I think it is a subject that we are going to have with us forever, and I also think that our Society and all other societies dealing with power should make an effort to educate all industrial plant officials and engineers on the importance of installing the proper equipment to promote unity power factor.

W. H. Burr, As Mr. Schnure has intimated, this power factor problem has been with us for some time, and will be with us for some time to come. I do not think any organization in this community has had more to do with the education of electrical engineers than the Philadelphia Electric Company. When a clause in a power contract is made effective and the cost of purchased power is increased, right then the power factor problem is given consideration.

Most companies have given careful consideration to the use of synchronous motors to increase the power factor in their power systems but not many installations as large as the one described by Mr. Schnure, at Bethlehem Steel Co., at Sparrows Point, operate at unity power factor.

With the increasing use of Electric Welding, consideration should be given to the application of synchronous motors to multiple operating welding sets. In many cases a saving can be effected in power cost and also in first cost and maintenance.

There is only one question I would like to ask the speaker of the evening. I am wondering if he has in his experience ever come across an installation where the power factor was leading to such an extent that it was necessary to install inductive load to bring it back to somewhere near unit power factor.

Mr. Gaskill has given us a paper this evening which is full of very valuable information and should make a very fine record for our Iron and Steel Engineer. I congratulate Mr. Gaskill on his paper.

N. C. Bye: In a case where there is a choice between correction at the source or group correction, does the utility company recommend where it should be applied?

J. F. Gaskill: No.

N. C. Bye: You leave that up to the customer?

J. F. Gaskill: Yes.

R. F. Gale: Like Mr. Schnure, I too know that many persons do not understand what is meant by Power Factor. In answer to a question as what certain pieces of apparatus were for, I explained they were Condensers, and used for Power Factor Correction. This immediately resulted in my being called upon to define Power Factor. I resorted to the age-old analogy—Power Factor versus Glass of Beer. A person pays for the full glass of beer made up of liquid and froth. The effective part of the contents of this glass of beer is the liquid and not the froth. My questioner immediately got the point and I am sure never forgot what a Power Factor was.

Mr. Gaskill certainly covered every possible application. I know of a case where his point that Power Factor correction very often eliminates the necessity of increased investment. A business friend of mine buying his power from a Public Utility found it necessary to add motors. He avoided a considerably extra expenditure by installing Power Factor corrective apparatus.

As stated by previous speakers, no single prescription is available for Power Factor correction. Each problem must be treated separately and distinctly, all of which I feel the speaker—Mr. Gaskill—has pointed out very thoroughly.

F. F. Herrmann: Does the power factor of one plant affect the power factor of the adjoining plant on the same line?

J. F. Gaskill: No. The effect of one plant ceases entirely at that plant and does not affect the power factor of other plants. If we correct the power factor of one plant, correction does not affect the power factor of other plants on the same line.

COMBUSTION TOPICS

Furnace repairs add approximately one dollar to the cost of each ton of steel produced. From the standpoint of design, operation and maintenance, a goodly proportion of our readers are vitally interested in this item of cost. To meet this interest, we start our new department, "Combustion Topics", with a series of informative articles on furnace materials, beginning with the most important item, refractories.

SELECTION OF REFRACTORIES

Camp & Francis, in "The Making, Shaping and Treating of Steel" have set up the perfect refractory as one that, at any required temperature, will not fuse or soften, crumble or crack, with minimum heat conductivity, contraction and expansion. It should be impermeable to gases and liquids, should resist mechanical abrasion, and have no chemical reaction with substances with which it is in contact. Needless to say, the perfect refractory does not exist. The various refractories possess the foregoing qualities in widely varying degrees, and it is necessary to select the refractory that best meets the requirements.

The causes of refractory failure are summarized by Searle, "Refractory Materials", as follows:

A. Crumbling, caused by bricks being too weak (or excessively porous) at high temperature.

B. Shattering, due to the material being too weak, or too fine and overburned, so it cannot resist sudden changes in temperature.

C. Abrasion, mechanical erosion by movement of contents of the furnace. Abrasion of exposed bricks by flue dust accompanied by vitrification will wear away a brick, however refractory it may be.

D. Vitrification, or partial fusion caused by excessive heating, or by combination of ash or other material with the brick, thus producing a compound of lower fusion-point than the brick alone. No matter how thoroughly a brick has been burned, constant exposure to very high temperature will cause still further shrinkage.

E. Internal strains, due to alternate heating and cooling of the furnace, and to any chemical or physical changes in the material which may result from prolonged heating. Among the most important are strains due to shrinkage or expansion of refractory material when in use. If the refractory material is a good conductor of heat, these are not serious unless the furnace is driven excessively hard. Rapid temperature changes should be avoided when possible. Burning refractory materials at temperatures well above those at which chief volume changes occur, and allowing sufficient time for completion of the change will reduce strains.

F. Corrosion, by flue dust, slag or other substances having chemical action on the refractory material. Chemical corrosion is due to improper chemical composition of the refractory material. External corrosion is due to incompatibility between the refractory material and the gases or other substances with which it comes into contact.

There is another type of failure, which should be considered; that of failure of mechanical support. For example, when a section of a refractory surface fails, it is always necessary to replace more bricks than are actually damaged. This is really a secondary factor, but in modern boiler furnaces, with their high walls, it is a very important one.

Failures are usually due to a combination of causes. It is rare that one specific factor can be definitely pointed out as the sole cause of refractory failure.

The selection of refractories for specific installations must therefore embrace considerations as follows:

1. What is the highest temperature to which the brick will be exposed, and will it be constant or fluctuating? Must the brick withstand sudden and repeated changes in temperature?
2. Will the refractory come into direct contact with any flame, and will the flame be oxidizing or reducing?
3. What mechanical strength is required?
4. Is heat to be conducted or retained?
5. Will brick come into contact with fluid slags, flue dust, or other fluxes? What is the nature and composition of such materials?
6. Must the brick withstand blows, shocks, or other strains?
7. What is the nature of the fuel, and how is it fed?
8. Is electrical conductivity important?

For the first consideration given above, refractoriness is important, while a lean, coarse, porous material better withstands temperature changes. For the second and third items, texture and surface conditions must be considered. Great mechanical strength is obtained only at the expense of refractoriness. The fourth item, of course, embraces heat conductivity of the refractory, while the fifth consideration takes in the texture and composition of the material. A hard, close material better resists slag, at the expense of resistance to temperature changes, while the refractory must be of a chemical nature similar to the material in contact with it. The sixth item considers the grain and burn of the refractory. The seventh item is really a combina-

tion of items two and five, while the last point is self-explanatory.

The selection of refractories can perhaps best be discussed by consideration of the requirements of specific uses.

STOVES, REGENERATORS AND RECUPERATORS:

Bricks for these uses must have sufficient refractoriness to withstand prevailing temperatures. The chief cause of low durability is the decomposition of bricks by gases, dust, etc. The bond of the brick must withstand chemical action of the gases. High heat conductivity is desirable, so as to obtain good heat capacity and transfer. Mechanical strength is particularly important in stoves, due to the weight of material that must be carried. A low coefficient of expansion is desirable, so as to avoid disintegration, while the temperature changes inherent in stove or regenerator operation requires insensitiveness to sudden changes in temperature.

These requirements in some cases call for directly opposite characteristics in the brick. The best results seem to be obtained from first quality firebrick, of medium grind and a high medium burn. Close-textured brick have better heat conductivity characteristics, but are more sensitive to temperature fluctuation, than a more porous brick.

Table I reports results of tests on the heat given up in cooling by bricks of different material.

BLAST FURNACE:

From bottom to top of the blast furnace, the requirements that must be met by the refractories are widely different. The hearth and bosh are subjected to very high temperatures, and to slagging action. The inwall must withstand scoring action at somewhat elevated temperature, while the top must resist serious abrasion. To meet these conditions, hearth and bosh bricks are made with a relatively large proportion of flint clay and a correspondingly small proportion of plastic clay. Iron and alkali contents must be a minimum. Inwall bricks usually carry a greater proportion of plastic clay than hearth and bosh bricks. Top bricks are made with a large proportion of plastic clay, pressed very hard, and burned to great density. Some of them resemble vitrified paving brick almost as much as they do firebrick.

OPEN HEARTH: (Basic)

The open hearth imposes the most varied requirements on refractories of any furnace. The hearth must be extremely refractory, and must resist the scouring action of the bath and slag, and must be easily repaired. The walls must resist high temperatures, the cutting action of the flame, and the splashing of slag and metal. Roof brick must have strength and rigidity sufficient to withstand the arch stresses at extremely high temperatures, and must also resist chemical attack by the basic oxides absorbed from the hot gases. End walls and bulkheads are subjected to severe scouring action of dust particles in the rapidly moving gases.

The hearth is usually built up with a base of firebrick, perhaps a course of chrome brick next, then a course or two of magnesite brick, with a bottom of dead-burned magnesite sintered over the top. The roof is commonly built of silica brick. Sidewalls are of silica brick above the bath line, with magnesia brick often used below, sometimes with a layer of chrome brick between. End walls and bulkheads are commonly built of silica brick, as are the slag pockets. Bulkheads, end-walls and ports are sometimes lined with magnesite brick.

BOILER FURNACES:

Boiler furnaces are built almost entirely of first and second grade fire brick. However, the conditions of service vary widely, depending on type of boiler, furnace design, kind of fuel, method of firing, and operating practice. The refractory may be called on to withstand high temperature, rapid temperature changes, slag erosion and fluxing, and abrasion in varying degrees. Table II shows the causes of failure of refractories in boiler furnaces with different fuels, taken from Bulletin No. 334, U. S. Bureau of Mines. Due to the apparent simplicity of the application, it is only comparatively recently that effort has been made by refractory manufacturers and engineers to investigate failures in boiler furnaces with the idea of improving service by use of refractories with characteristics to meet the conditions of the specific installation.

FORGE AND HEATING FURNACES:

Furnaces of this type are usually built of a good grade of firebrick. Roofs should be of a coarse, porous brick to withstand temperature changes, while the hearth should be of dense, hard brick to withstand abrasion. With exceedingly high temperatures, however, firebrick are subject to vitrification, shrinkage and spalling. Bricks made from a good grade of diaspore work well in high temperature furnaces. Slag resisting properties are good, but a comparatively large shrinkage occurs at high temperatures. Sillimanite is very refractory, and is not subject to shrinkage or vitrification. Spalling properties are good. It is very satisfactory for the upper parts of very high temperature heating furnaces. Chrome refractories are well suited for use in hearths because of their resistance to the solvent action of iron oxide even at high temperatures. They may be in the form of brick, cement, or the loose ore.

COKE OVENS:

In modern ovens, the entire battery structure above floor level, except the top paving and outside facings, are of high grade silica brick. Regenerators and checkers are of high grade firebrick.

ELECTRIC FURNACES:

The roofs of electric furnaces, whether in basic or acid practice, are usually of silica brick, as are the sidewalls. In basic steel furnaces, the bottom part of the sidewall may be of magnesia brick as is the hearth, over which a basic bottom of magnesite or dolomite is sintered into place. Acid electric steel furnace bottoms are of silica brick.

HEAT TREATING FURNACES:

The demands placed on various furnaces which are commonly placed under this heading are so varied that it is difficult to generalize. However, first and second quality firebrick is the usual refractory. High alumina refractories are often used where resistance to deformation or shrinkage under heavy load at high temperatures is required. Carborundum refractories are sometimes used for hearths, muffles or other parts requiring high heat conductivity.

CONVERTERS are lined with silica or magnesia brick, according to whether the practice is acidic or basic.

GAS PRODUCERS are lined with first or second grade firebrick.

LADLES are commonly lined with a good grade of firebrick. Its refractoriness should be at least 3050° F.

An interesting table of the consumption of refractories has been given by Mr. M. C. Booze, showing the various uses in percent of the total. (See Table III.) It is apparent that the iron and steel industry is the heavy consumer, using more than 60% of the total. Of these, the large users are the blast furnace, the open hearth, the by-product coke plant, heating furnaces and boiler furnaces. Data assembled from various sources on the consumption of these units are as follows:

Blast furnaces, stoves and connections—15 lb. of firebrick per ton of pig iron.

Open hearth furnaces—15 lb. of firebrick, 30 lb. of silica brick, 4 lb. of magnesite refractories, 1 lb. of chrome refractories per ton of steel.

Coke plants—3 lb. of firebrick, 7 lb. of silica brick per ton of coke.

Heating furnaces—4-5 lb. of firebrick per ton of steel.

Boiler furnaces—About 6 lb, of firebrick per thousand boiler HP. output.

Table IV, taken from Bulletin No. 334, U. S. Bureau of Mines, gives the brick consumption of boiler furnaces with various fuels.

TABLE I.

BTU GIVEN UP DURING COOLING OF BRICK

Cooling Time, Min.	Silicon Carbide	Silica	Clay High Porosity	Clay, Low Porosity
10	750	1500	1600	1700
20	1450	2100	2400	2500
30	2000	2500	2750	2920
40	2400	2850	3050	3250
50	2700	3100	3350	3550
60	2900	3200	3650	3900

TABLE II.

CAUSES OF FAILURE OF REFRACTORIES IN BOILER FURNACES

(In average order of importance)

FUEL	CAUSE OF FAILURE
Low and medium volatile Eastern bituminous coal with ash of high softening temperature	1. Slag adhesion 2. Failure of structure 3. Slag erosion 4. Spalling
High volatile Eastern bituminous coal with ash of high softening temperature	1. Slag adhesion 2. Failure of structure 3. Spalling 4. Slag erosion
High volatile Eastern bituminous coal with ash of low softening temperature, burned on underfeed stokers	1. Slag adhesion 2. Slag erosion 3. Failure of structure 4. Spalling
High volatile Eastern bituminous coal with ash of low softening temperature, burned on traveling grates	1. Slag erosion 2. Spalling 3. Failure of structure
Illinois coal burned on traveling grates	1. Slag erosion 2. Spalling 3. Failure of structure
Anthracite burned on traveling grates	1. Failure of structure 2. Spalling 3. Slag erosion
Fuel oil	1. Spalling 2. Slag erosion 3. Failure of structure
Powdered coal	1. Slag erosion 2. Failure of structure 3. Spalling

TABLE III.

CONSUMPTION OF REFRACTORIES

USE	PERCENT OF TOTAL			
	Clay Brick	Silica Brick	Other Refractories	Total
Blast furnaces and stoves	6.3	.....	.....	6.3
Open hearth furnaces	12.1	21.0	1.0	34.1
Heating furnaces	6.8	.5	.01	7.3
Crucible furnaces	.1	.2	.01	.3
Electric furnaces	.2	.3	.04	.5
Cupola furnaces	2.3	.....	.....	2.3
Malleable furnaces	2.4	.....	.....	2.4
Bee-hive coke ovens	.6	.3	.....	.9
By-product coke ovens	2.4	3.7	.....	6.1
Non-ferrous smelting	1.8	1.0	.1	2.9
Boiler furnaces	19.45	.....	.05	19.6
Gas plants	2.0	2.4	.....	4.4
Chemicals plants	1.0	.....	.....	1.0
Cement plants	1.8	.....	.1	1.9
Lime plants	1.5	.2	.....	1.7
Glass plants	2.1	1.0	.....	3.1
Ceramic kilns	2.5	.....	.....	2.5
Miscellaneous	2.1	.5	.1	2.7

TABLE IV.

AVERAGE NUMBER OF BRICKS USED IN BOILER FURNACES WITH VARIOUS FUELS

FUEL	No. of groups averaged	9-inch bricks per billion BTU output of boiler		
		Maximum	Minimum	Average
Oil	8	36	9	24
Anthracite	2	12	3	7.5
Medium and low volatile Eastern bituminous coal (1)	28	54	4.5	24
High-volatile, refractory ash, Pittsburgh coal (1)	5	18	6	12
High-volatile, fusible ash, Pittsburgh coal (1)	2	42	24	33
High-volatile, fusible ash, Illinois coal (2)	11	39	6	24
Pulverized Pittsburgh coal	1	.....	.....	24

(1) Burned on underfeed stokers, with high side walls.
(2) Burned on traveling grates, with low side walls.

ITEMS OF INTEREST

PERSONNEL CHANGES

▲

A. L. Freret has been appointed Chief Electrical Engineer of the Tennessee Coal, Iron and Railroad Company succeeding J. E. Fries, deceased. C. W. Harrison has been appointed Assistant Chief Electrical Engineer. The A. I. & S. E. E. membership offer their sincerest congratulations to these well known engineers for their advancement and extend their best wishes for their success in their new positions.

▲

Personnel changes, effective September 1 in the Duquesne plant of the Carnegie Steel Company were announced. K. H. McLaurin, formerly Master Mechanic, was appointed Chief Mechanical Engineer, succeeding Thomas P. Davies, retired. T. E. Hughes, formerly Assistant Superintendent of the Electrical Division and more recently Acting Superintendent, was named Chief of the Maintenance and Mechanical Department. His assistants will be R. H. Currie and R. F. Sanner. The A. I. & S. E. E. offer their congratulations and extend their best wishes to these men for their continued success in their new capacities.

▲

Colt's Patent Fire Arms Manufacturing Company of Hartford, Conn., announce the appointment of the H. B. Squires Company, 1277 Howard street, San Francisco, Cal., as their Pacific Coast selling representatives, effective as of August 1. Adequate stocks will be maintained in San Francisco, Los Angeles and Seattle.

▲

Thomas M. Jones has been appointed General Sales Manager of the Keystone Lubricating Company, Philadelphia, Pa. Mr. Jones' activities in company work for a period of fourteen years, heretofore as advertising counsellor and recently as merchandising advisor have been of a kind and character of considerable benefit to the Keystone Lubricating Co., in developing their distributor sales policy which they have adopted and through which they are now functioning.

▲

J. W. Speer, formerly Manager, Machinery Electrification, Industrial Department, Westinghouse Electric and Manufacturing Company, has been appointed Manager, Commercial Air Conditioning Products of the company with offices at the East Pittsburgh Works.

▲

OBITUARIES

C. A. Menk, formerly Electrical Superintendent of the Homestead Works of the Carnegie Steel Company, Munhall, Pa. died August 22nd at his home 15 Club avenue, Brentwood, Pa after a short illness. Mr. Menk entered the employ of the Carnegie Steel Company at Homestead in 1891 under the supervision of the late Alva C. Dinkey then Superintendent of the Electrical Department. Mr. Menk made steady advancement in the profession of applying electricity to the manufacture of Iron and Steel and in 1905 was made Superintendent of the Electrical Department succeeding S. S. Wales who was promoted to the superintendency of the Armor Plate Department. Mr. Menk served as the Electrical Superintendent up until his retirement in 1930.

C. A. MENK

He was an active member of the A. I. & S. E. E. since its inception in 1907. He served on many national committees of the Association and was elected to the Presidency of the Society in 1918. Mr. Menk made many valuable contributions to the Proceedings of the Association among them being: Apprentice Systems, Electrical Repair Shop and Electrical Installations New Structural Mills, Homestead Works, Carnegie Steel Company, Munhall, Pa.

Mr. Menk was signally honored at the Twenty-third Convention of the A. I. & S. E. E. held in Pittsburgh in 1927 when he was presented with a plaque from the Board of Directors and Membership in recognition of his distinguished service to electrical progress in the Iron and Steel Industry in connection with the engineering, construction and operation of the structural mills at the Homestead Works of the Carnegie Steel Company.

The A. I. & S. E. E. wishes to take this opportunity of expressing their deepest sympathy to the family and friends of this nationally known engineer.

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Fred W. Sinram, prominent in the gear manufacturing industry, died at Cleveland, Ohio, August 3, 1932.

Mr. Sinram was one of the founders of the American Gear Manufacturers' Association in 1917, and served continuously as its first President for seven years.